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Contribution to the knowledge of marsh vegetation of montane and submontane areas of Northern Apennines (Italy)

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Abstract

Freshwater ecosystems are crucial for biodiversity conservation. They are among the most threatened habitats in the world. However, the wetlands of southern European mountains still lack fine-scale plant community studies. Here we studied submontane and montane palustrine communities of the Tuscan-Romagna Apennines. Data from 123 vegetation plots dominated by palustrine species were analysed by means of cluster analysis. We identified 18 vegetation types that we attributed to five classes (*Phragmito-Magnocaricetea, Montio-Cardaminetea, Isoëto-Nanojuncetea, Molinio-Arrhenatheretea*, and *Epilobietea angustifolii*), and to two Natura 2000 habitats (3130 - Oligotrophic to mesotrophic standing waters with vegetation of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*, and 6430 - Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels). According the 4th edition of the International Code of Phytosociological Nomenclature we corrected the names *Phragmition communis* Koch 1926 *nom. inept.* in *P. australis* Koch 1926 *nom. corr.*, *Phragmitetum communis* Savič 1926 *nom. inept.* in *P. australis* Savič 1926 *nom. corr.*, *Glycerietum plicatae* Kulczyński 1928 *nom. inept.* in *G. notatae* Kulczyński 1928 *nom. corr.*, *Beruletum angustifoliae* Roll 1938 *nom. inept.* in *Beruletum erectae* Roll 1938 *nom. corr.*, and we mutated the name *Scirpetum lacustris* Chouard 1924 *nom. inept.* in *Schoenoplectetum lacustris* Chouard 1924 *nom. mut. nov*. Our study highlights the diversity of marsh vegetation of montane and submontane areas of Northern Apennines. Most of the palustrine communities, though important from the point of view of conservation, cannot be attributed at present to any habitat type legally protected at the European level.

Keywords

Conservation, freshwater ecosystem, palustrine habitat, phytosociology, syntaxonomy, vegetation

Introduction

Wetlands are crucial for biodiversity conservation as they provide suitable habitats for numerous threatened plant species and communities (Zhang et al. 2012). Despite that, they are among the most threatened habitats in the world, mainly by human pressures, such as overexploitation, water pollution, flow modification, destruction or degradation of habitat, and alien species invasion (Dudgeon et al. 2006; Hrivnák et al. 2014). This worrying

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trend is rapidly increasing in the last few years (Reid et al. 2018). In Europe, and in Italy, freshwater ecosystems include many threatened habitats with an unfavorable conservation status (Janssen et al. 2016; Zivkovic et al. 2017; Gigante et al. 2018; Lazzaro et al. 2020; Viciani et al. 2020; Gennai et al. 2021). Nevertheless, several wetland plant communities of conservation relevance are not included in the Habitats Directive, nor in any other protection list, although extremely rare, especially in the Mediterranean Basin (Gigante et al. 2013; Benavént-Gonzales et al. 2014; Lastrucci et al. 2014, 2017a, 2019; Angiolini et al. 2017; Casavecchia et al. 2021). Wetlands in the Apennines are often fragmented and floristically impoverished (Angiolini et al. 2019). Moreover, many Apennine freshwater ecosystems are partially or totally of artificial origin, being related to anthropogenic activities, especially at relatively low elevations (Gerdol and Tomaselli 1993). Despite this, such wetlands, including many artificial ones, can be highly relevant for plant diversity and conservation (Hrivnák et al. 2014; Viciani et al. 2022).

Studies of wetland vegetation at high-elevation areas of the Tuscan Apennines are available (Gerdol and Tomaselli 1993), while relatively few works have investigated low-elevation areas of the Northern Apennines, between Eastern Tuscany and Romagna (see Viciani et al. 2022 for aquatic vegetation). To fill the gap of knowledge for this area, we present our contribution concerning the marsh vegetation.

Material and methods

Study area

The study area is located in the northeastern Apennines between Tuscany and Emilia-Romagna regions (Central Italy, Fig. 1). It encompasses 45 wetlands sites, ranging from 535 m up to 1,470 m a.s.l., partially located in the Foreste Casentinesi National Park and in some Special Areas of Conservation belonging to Natura 2000 network (Appendix I). These wetlands include artificial lakes, small ponds, pools, marshes, and wet meadows. The climate is generally submontane/montane, with mesic temperatures and moderate to heavy rainfall, depending on the elevation. The study area has a temperate oceanic bioclimate at higher elevations and a temperate oceanic-submediterranean bioclimate at lower elevations (Pesaresi et al. 2017). As for geological substrates, there are four main geological formations in the area (Carmignani et al. 2013): three on the Tyrrhenian-facing slopes, with two types of siliceous sandstones, with different percentages of limestone and silty schists ("Macigno del Chianti" and "Macigno del Mugello"), and limestone outcrops ("Alberese"); and one, a sandstone-marly flysch formation ("Marnoso-arenacea") is widespread in the Adriatic-facing slopes. Other less extensive geological formations are also present (Carmignani et al. 2013).

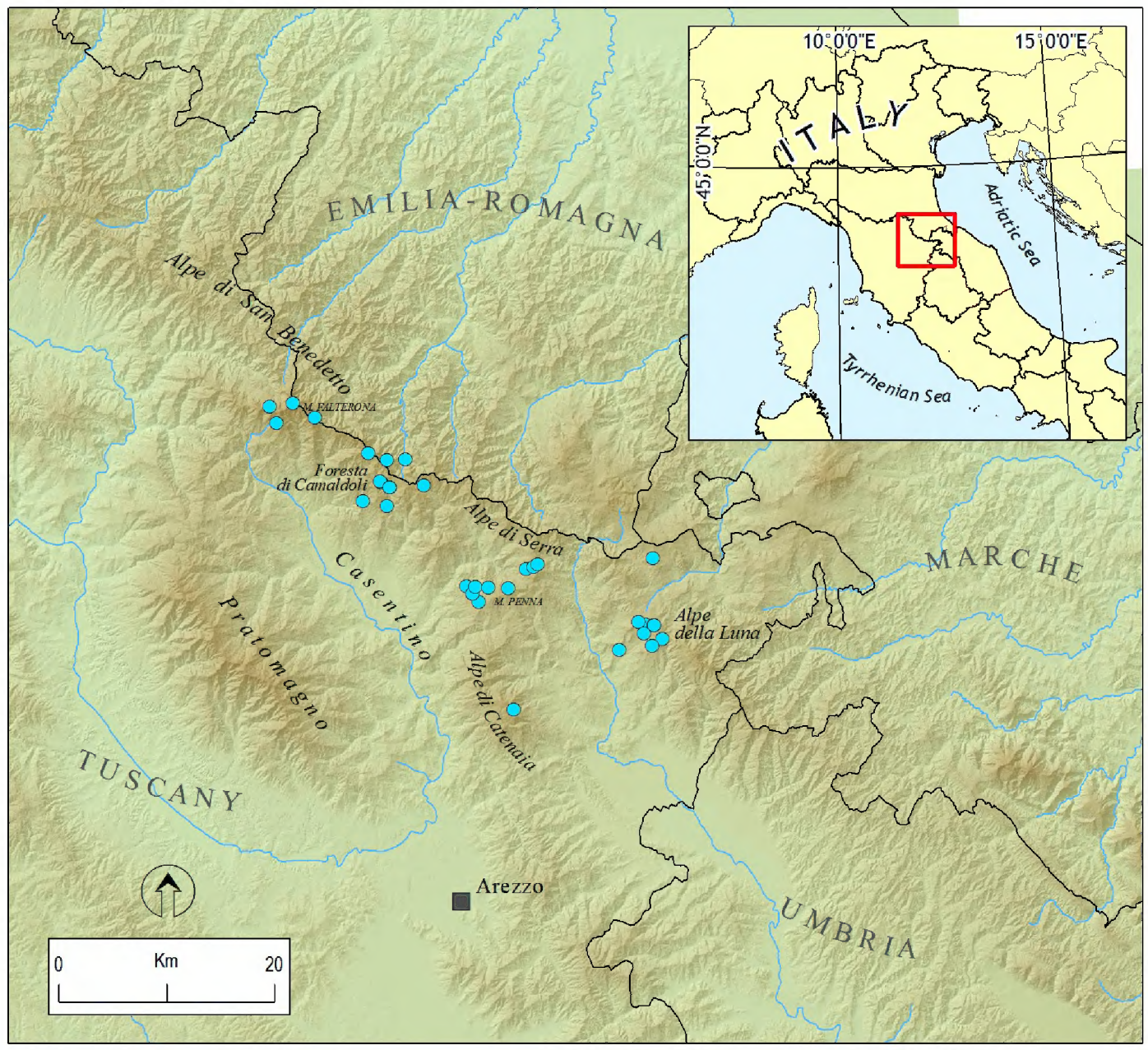

Figure 1. Study area and its position in respect to Italy (inset in the upper right corner). Circles are the investigated sites.

Data set and data analysis

Our dataset is composed of 123 relevés (N = 109 original; N = 14 published; Lastrucci et al. 2005) concerning plant communities dominated by palustrine species. Data have been collected in the years 2005-2019 following the phytosociological method (Braun-Blanquet 1932). Site names, site abbreviations used in the relevé tables, coordinates, elevation, inclusion in protected areas and references concerning published data, are available in Appendix I. We analysed a matrix of 123 relevés × 164 species using a cluster analysis in R environment (R Core Team 2020), using the chord distance of the function *vegdist* of ´vegan´ package (Oksanen et al. 2020) and median linkage of the function hclust of ´stats´ package (R Core Team 2020). Data was transformed using the Van der Maarel scale. Plant species names mainly follow the Portal to the Flora of Italy (2022), while the syntaxonomic nomenclature of classes, orders, and alliances follows mainly the Vegetation of Europe by Mucina et al. (2016), and the Italian Vegetation Prodrome (Biondi and Blasi 2015). The names of the syntaxa have been corrected and mutated when necessary in agreement with the 4th edition of the ICPN (Theurillat et al. 2021).

Results and discussion

The dendrogram resulting from the cluster analysis (Fig. 2) allowed us to identify 18 different plant communities. From a syntaxonomic viewpoint, they can be classified to five different classes: *Phragmito-Magnocaricetea*, *Montio-Cardaminetea*, *Isoëto-Nanojuncetea*, *Molinio-Arrhenatheretea*, and *Epilobietea angustifolii*. In the following sections, the communities are described and commented.

Marsh vegetation communities

PHRAGMITETUM AUSTRALIS Savič 1926 *nom. corr.* (Suppl. Material 1, Table S1, rels 1–8, Group 13 in Fig. 2) (*Phragmitetum communis* Savič 1926 *nom. inept.*)

Nomenclatural notes: The name reported by Savič (1926) is *Phragmitetum communis* according the taxon name *Phragmites communis* Trin. 1820. In the current floras of most countries worldwide (see Euro+Med 2023; POWO 2023) the accepted name of this taxon is *Phragmites australis* (Cav.) Steud. 1840, therefore we corrected the name in *Phragmitetum australis* Savič 1926 *nom. corr.*

Phragmites australis forms dense species-poor stands, along submerged and emergent shores of lakes, swamps, pools, ponds, riverbanks, and channels (Landucci et al. 2013). The association is rather widespread in Italy (Landucci et al. 2013). In several wetlands of Central Italy, it seems affected by the die-back syndrome (Lastrucci et al. 2017a). In the study area, *P. australis* is not very common and we found it only at three sites, where it grows in temporarily submerged conditions. Less dense stands can be interpreted as transitional vegetation towards communities belonging to alliance *Glycerio-Sparganion*.

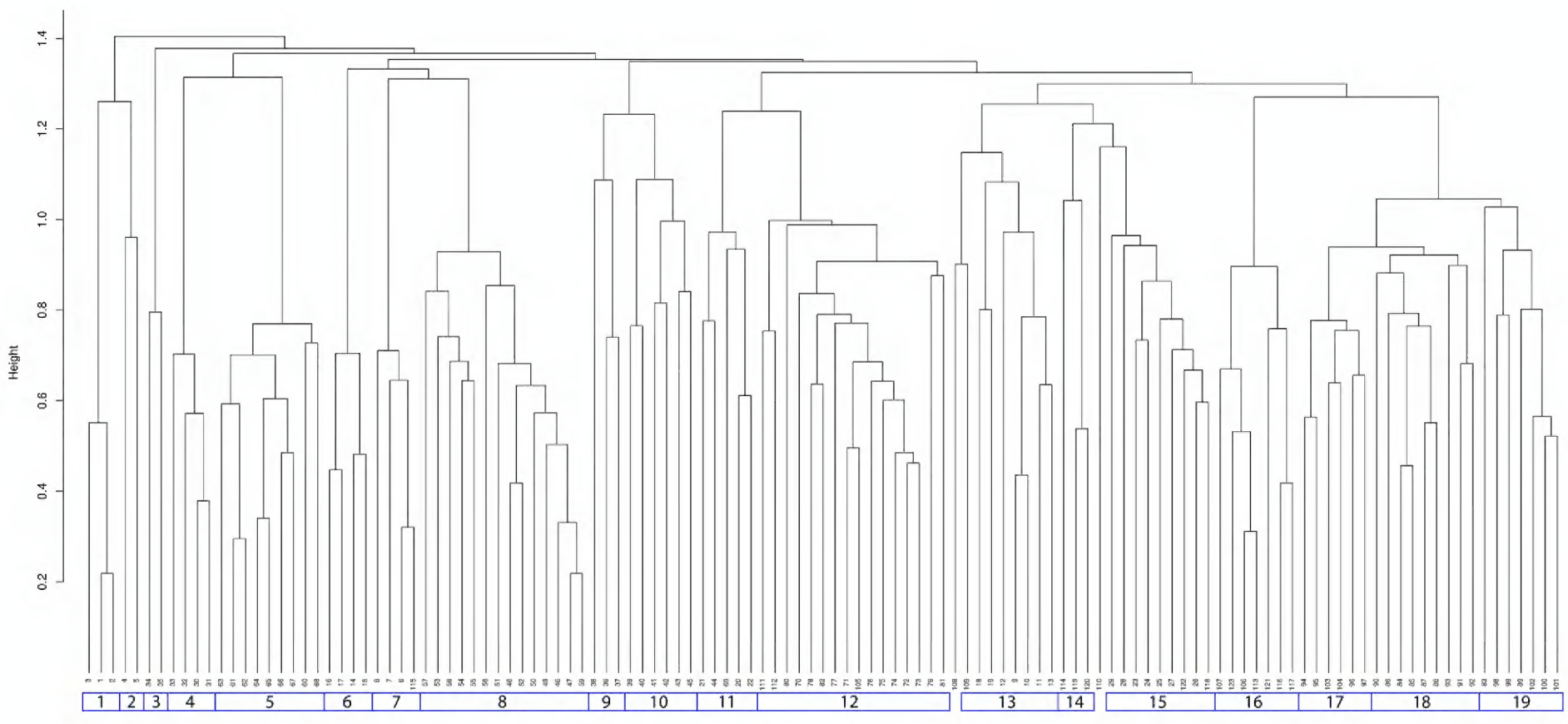

Figure 2. Cluster dendrogram of our data encompassing 123 relevés of palustrine vegetation of montane and submontane areas of Northern Apennines (Italy). Relevés groups: 1, *Typhetum angustifoliae*; 2, *Schoenoplectetum lacustris*; 3, *Peplis portula* community; 4, *Glycerietum fluitantis*; 5, *Eleocharitetum palustris*; 6, *Caricetum vesicariae*; 7, *Typhetum latifoliae*; 8, *Glycerio-Sparganietum neglecti*; 9, *Caltha palustris* community; 10, *Heracleo ternati-Petasitetum hybridi*; 11, *Beruletum erectae*; 12, *Glycerietum notatae*; 13, *Phragmitetum australis*; 14, *Equiseto palustris-Juncetum effusi*; 15, *Caricetum remotae*; 16, *Cardamine amara* community; 17, *Carici otrubae-Juncetum inflexi* variant with *Juncus effusus*; 18, *Carici otrubae-Juncetum inflexi*; 19, *Carici otrubae-Juncetum inflexi* variant with *Equisetum palustre*.

SCHOENOPLECTETUM LACUSTRIS Chouard 1924 *nom. mut. nov.* (Suppl. Material 1, Table S1, rels 9–10, Group 2 in Fig. 2)
(*Scirpetum lacustris* Chouard 1924 *nom. inept.*)

Nomenclatural notes: The name reported by Chouard (1924: 1136-1137) is "Association à *Scirpus lacustris*" according to the taxon name *Scirpus lacustris* L. 1753. Currently *Scirpus lacustris* is included in the genus *Schoenoplectus* and its name is *Schoenoplectus lacustris* (L.) Palla 1888 (Euro+Med 2023; POWO 2023). Therefore, we introduce the new name *Schoenoplectetum lacustris* Chouard 1924 *nom. mut. nov.*

This association, with a strong pioneer feature, is reported for several habitat types such as on shores of mesotrophic to eutrophic lakes, ponds, or channels, usually growing in deeper water than other types of reed vegetation (Poldini 1989; Landucci et al. 2013; Lastrucci et al. 2019). In the study area, it grows catenal to the association *Typhetum angustifoliae*. Rarely, *Schoenoplectus lacustris* forms large dense stands, sometimes accompanied by *Schoenoplectus litoralis*, which can also reach high cover locally. *S. litoralis* usually forms stands in slightly to moderate halophilous habitats (e.g., Curcó i Masip 2001; Brullo and Sciandrello 2006), but the presence of this species in the freshwater wetlands of the Northern Apennines was highlighted by Lastrucci and Raffaelli (2006).

TYPHETUM LATIFOLIAE Eggler 1933 (Suppl. Material 1, Table S1, rels 11–14, Group 7 in Fig. 2)

Nomenclatural notes: The name *Typhetum latifoliae* Nowiński 1930 is actually invalid, as it was originally published not at the rank of association but as a subassociation of the *Scirpo-Phragmitetum* (see Nowiński 1930); the first validly published name for these communities resulted to be *Typhetum latifoliae* Eggler 1933.

This association is very common in Italy and develops in several different habitats, such as ponds, lakeshores, banks of slow-flowing streams, deltas, swamps, and channels (Landucci et al. 2013), and it tolerates the summer drying (Šumberová et al. 2011). In the study area, the association forms more or less dense stands around ponds. The association is often very poor in species or even monospecific (Hrivnák 2004; Fernez and Causse 2015). This feature is also confirmed within our study area.

TYPHETUM ANGUSTIFOLIAE Allorge ex Pignatti 1953 (Suppl. Material 1, Table S1, rels 15–17, Group 1 in Fig. 2)

This association is typical of several wetland types on mesotrophic to eutrophic waters, often monospecific or species-poor (Landucci et al. 2013). Though the association is rather common in Italy (Landucci et al. 2013 and references therein), and in Tuscany (Lastrucci et al. 2010a; Mereu et al. 2012; Lastrucci et al. 2017b), it was found only at two sites of our study area, forming stands on flooded soils. According to the ecological features of this association, the surveyed stands appeared monospecific or species-poor.

CARICETUM VESICARIAE Chouard 1924 (Suppl. Material 1, Table S1, rels 18–21, Group 6 in Fig. 2)

Large sedge vegetation is not widespread in the study area. We found only one patch, corresponding to a community attributable to *Caricetum vesicariae*, typical of mesotrophic to eutrophic habitats, permanently flooded for most of the year (Landucci et al. 2013). Within the association, variants typical of marshlands and wet meadows can be often identified (Buchwald 1994; Hrivnák 2004; Lastrucci et al. 2008). In the study area, the association is catenal to communities of the alliance *Glycerio-Sparganion* (associations *Glycerietum fluitantis* and *Glycerio-Sparganietum*), but in some relevés, together with typical marsh plants, also a pool of species typical of wet meadows is present (*Agrostis stolonifera*, *Rumex conglomeratus*, *Ranunculus repens*).

GLYCERIO-SPARGANIETUM NEGLECTI Koch 1926 (Suppl. Material 1, Table S2, rels 1–14, Group 8 in Fig. 2; Fig. 3A)

According to Landucci et al. (2013), this association includes both *Sparganium erectum* subsp. *erectum* and *S. erectum* subsp. *neglectum* communities. However, a recent genetic study also highlighted a putative intraspecific hybridization among subspecies (Píšová and Fér 2020) The stands dominated by *S. erectum* s.l. can be attributed to this association (Šumberová et al. 2011; Landucci et al. 2013). *S. erectum* communities are usually located in the ecological transition between the *Phragmition* and *Glycerio-Sparganion* communities, so their attribution to the alliance level is not always univocal (Buchwald 1994; Landucci et al. 2013; Landucci et al. 2020).

In the study area, the association forms dense belts around ponds, developing in habitats with strong fluctuations of water levels, similar to *Glycerietum fluitantis* or *Glycerietum notatae*, and less flooded than those occupied by *Phragmition* communities, justifying our attribution to the alliance *Glycerio-Sparganion*. At some sites, the association also occurs in trampled and disturbed habitats, hosting species of wet meadows such as *Poa trivialis*, *Ranunculus repens*, and *Rumex conglomeratus*.

GLYCERIETUM NOTATAE Kulczyński 1928 *nom. corr.* (Suppl. Material 1, Table S2, rels 15–30, Group 12 in Fig. 2)
(*Glycerietum plicatae* Kulczyński 1928 *nom. inept.*)

Nomenclatural notes: The name reported by Kulczyński (1928) is "*Glycerietum plicatae*" according the taxon name *Glyceria plicata* Fr. 1839. Currently the accepted name for this taxon is *Glyceria notata* Chevall. 1827 (Euro+Med 2023; POWO 2023), therefore we corrected the name in *Glycerietum notatae* Kulczyński 1928 nom. corr.

This association occurs in several habitat types such as riverbanks, channels in arable lands, natural and artificial ponds, and depressions in wet meadows, where it is often in contact with other communities of alliance *Glycerio-Sparganion* (Landucci et al. 2013).

This association is rather common in Italy (Landucci et al. 2013). Accordingly, in our study area, it represents one

of the most widespread vegetation types. It has been generally found around small ponds or watering holes, but it can also develop in less humid and disturbed sites, showing, in this case, a higher floristic richness with species of wet meadows such as *Carex hirta*, *Juncus inflexus*, *Poa trivialis*, and *Ranunculus repens*.

GLYCERIETUM FLUITANTIS Nowinski 1930 *nom. inval.* (Suppl. Material 1, Table S2, rels 31–34, Group 4 in Fig. 2)

Nomenclatural notes: The name *Glycerietum fluitantis* Nowinski 1930 although extensively used in recent times and in the past, must be considered invalid according to the ICPN code (Theurillat et al. 2021) because published as a subassociation and not as association (see Nowińsky 1930). However, this nomenclature issue could not be solved in this study.

According to Landucci et al. (2013), this vegetation type is structurally and ecologically very similar to *Glycerietum notatae*, but *Glyceria fluitans* is less tolerant than *G. notata* to eutrophication and disturbance, leading the association *Glycerietum fluitantis* to be less common in Italy than *Glycerietum notatae*. This trend was also found in the study area and we recorded *Glycerietum fluitantis* at only two sites. Rarely, it forms stands in shallow waters with the presence of *Ranunculus trichophyllus*, or it is in contact with the association *Caricetum vesicariae*.

BERULETUM ERECTAE Roll 1938 *nom. corr.* (Suppl. Material 1, Table S2, rels 35–39, Group 11 in Fig. 2)
(*Beruletum angustifoliae* Roll 1938 *nom. inept.*)

Nomenclatural notes: The name reported by Roll (1938) is *Beruletum angustifoliae* according to the taxon name *Berula angustifolia* Mert. & W.D.J.Koch 1826. However this name is a *nomen illegitimum*. Therefore we corrected the name in *Beruletum erectae* Roll. 1938 *nom. corr.*

Berula erecta-dominated stands can be attributed to the association *Beruletum erectae*, though this species also tends to occur in other communities such as *Helosciadietum nodiflori* Maire 1924 (Lastrucci et al. 2005; Landucci et al. 2013). The association is typical of mesotrophic streams and channels characterized by slow-flowing waters (Landucci et al. 2013). In the study area, the association was found along two wetlands supplied by small streams. According to the cluster analysis, one relevé previously attributed to *Phalarido-Petasitetum hybridi* (Lastrucci et al. 2005), was attributed to *Beruletum*, being interpretable as a transition towards tall herb communities, present at the edge of the wetland.

ELEOCHARITETUM PALUSTRIS Savič 1926 (Suppl. Material 1, Table S2, rels 40–48, Group 5 in Fig. 2)

This association is dominated by *Eleocharis palustris* and shows a typical pioneer behavior, often developing in the wet soils emerging during the dry season (Venanzoni and Gigante 2000). In our relevés, we only found *E. palustris* subsp. *palustris*, but in the area, the presence of other subspecies is likely (Lastrucci et al. 2020). This association, typically species-poor, is rather common in Italy (Landucci et al. 2013). Even in our study area, it is one of the most widespread vegetation type, colonizing, often in narrow strips, the muddy areas surrounding the small pools and drinking troughs, often in conditions of disturbance due to the presence of livestock. Our relevés show that the association is catenal to communities of hydrophytes of open waters (*Chara vulgaris*, *Potamogeton nodosus*, *Ranunculus trichophyllus*; see also Viciani et al. 2022) reaching the shallow shores of the pools colonized by *Eleocharitetum palustris*.

CARICETUM REMOTAE Kästner 1941 (Suppl. Material 1, Table S3, rels 1–9, Group 15 in Fig. 2)

This association is typical of flooded depressions with irregular water regimes and gravely beds such as small streams irrigating the forest roads, and forest springs disturbed by animals (Valachovič and Janovicová 1999). Both shade-tolerant and hygrophilous species are present in the floristic composition of the association, sometimes together with a high cover of bryophytes (Kliment et al. 2008). In the study area, we found the association in humid depressions at the forest margins or in mountain forests, watered by seasonal streams or rainwater. Our relevés show the presence of diagnostic species of the association, such as *Carex remota* (dominant), *Schedonorus giganteus* or *Brachypodium sylvaticum*, as well as several forest species such as *Athyrium filix-femina* and *Ranunculus lanuginosus*; hygrophilous species such as *Juncus* spp. and *Galium palustre* subsp. *palustre;* and nitrophilous and shade-tolerant species such as *Urtica dioica* subsp. *dioica*.

CARDAMINE AMARA community (Suppl. Material 1, Table S3, rels 10–16, Group 16 in Fig. 2)

Cardamine amara communities have often been attributed to the class *Montio-Cardaminetea*, sometimes considering it as *C. amara* community (e.g. Gerdol 1993; Mariotti 1995), attributed to different associations such as *Cardaminetum amarae* (Rübel 1912) Br.-Bl. 1926 (Braun-Blanquet 1949) or *Cardamino-Chrysosplenietum alternifolii* Maas 1959. The latter is an association typical of springs surrounded by forests with a partially-closed herb layer, often characterized by a species-rich bryophyte layer (Kliment et al. 2008). However, in the study area, *C. amara*-dominated stands were rather impoverished in species of *Montio-Cardaminetea* and they were often found at the edge of ponds and pools, sometimes in contact with aquatic vegetation, especially in some areas where small ditches enter the pools. These stands seem to replace the communities of the alliance *Glycerio-Sparganion* in semi-shaded habitats. In accordance with Hájková and Hájek (2011), also in our study area, the *C. amara* communities thrive better in wetter conditions than those belonging to the association *Caricetum remotae*.

CALTHA PALUSTRIS community (Suppl. Material 1, Table S3, rels 17–19, Group 9 in Fig. 2)

Caltha palustris is a very rare species within the study area. It was found only at two sites, typically along little

streams where it forms stands rich in hygrophilous and shade-tolerant species. From a phytosociological and nomenclatural point of view, the syntaxonomic attribution of *C. palustris* communities is affected by the fact that in the past many infraspecific taxa, currently considered synonyms of *C. palustris* (e.g., *C. laeta* Schott, Nyman & Kotschy) were used to define the associations. Our communities show some ecological affinities with those reported by Valachovič and Janovicová (1999) and Kliment et al. (2008) in Central Europe under the name *Carici remotae-Calthetum laetae* Coldea 1978, typical of muddy alluvia of stream meanders, and small-sized forest springs on the low-elevation mountains of Slovakia. In addition, *C. palustris* can grow in different habitat types, such as the wet mown meadows of the alliance *Calthion palustris* (Mucina et al. 2016), including for example the association *Chaerophyllo hirsuti-Calthetum palustris* Balátová-Tuláčková 1985 (see Balátová-Tuláčková 2000). Nevertheless, the ecological features of *C. palustris* stands occurring in the study area, which grow in partially shaded habitats along rivulets originating from impluviums and springs, let us classifying our communities to the class *Montio-Cardaminetea*, where the presence of this species is rather frequent (Hájková and Hájek, 2011). The increasing forest coverage and the disturbance by anthropogenic activities and ungulates are critical factors for the occurrence of this vegetation type.

CARICI OTRUBAE-JUNCETUM INFLEXI Minissale et Spampinato 1985 (Suppl. Material 1, Table S4, rels 1–22, Group 18 in Fig. 2; Fig. 3B)
variant with *JUNCUS EFFUSUS* (Suppl. Material 1, Table S4, rels 11–16, Group 17 in Fig. 2)
variant with *EQUISETUM PALUSTRE* (Suppl. Material 1, Table S4, rels 17–22, Group 19 in Fig. 2)

The rushes with *Juncus inflexus* represent one of the most common types of plant communities in the study area. From a topological point of view, they generally occupy the outer belts of wet areas, frequently disturbed and trampled by livestock, or the humid depressions and lowlands temporarily flooded in winter at the edge of forest vegetation. From a phytosociological point of view, *J. inflexus* can rarely form communities in marsh environments such as *Galio palustris-Juncetum inflexi* described for Umbria by Venanzoni and Gigante (2000) or, more usually, wet meadows communities such as *Junco inflexi-Menthetum longifoliae* Lohmeyer 1953 (e.g., Pedrotti 2008) or *Carici otrubae-Juncetum inflexi* described from Sicily (Minissale and Spampinato 1985). For their floristic composition, and for the richness of *Molinio-Arrhenatheretea* species, the high frequency of *Carex otrubae*, and their ecological characteristics, we attribute our stands to the association *Carici otrubae-Juncetum inflexi*. This association, as reported by Minissale and Spampinato (1985) for Sicily, is in contact with the communities of the long submerged habitats (*Eleocharitetum palustris* or *Glycerio-Sparganion* communities). These communities are also known for southern Tuscany (Lastrucci et al. 2019). The analysis of the rush communities of the study area also shows two different aspects. The first one is represented by rush mixed relevés with the presence of *J. effusus*, lacking in the original relevés of the *Carici otrubae-Juncetum inflexi* (see Minissale and Spampinato 1985). The second one is represented by stands developing in depressions with water stagnation or with slight runoff at the edge of the forest. This vegetation type is differentiated by species of shady margins and/or indicators of high water availability, characterizing a more hygrophilous variant of the *Carici-Juncetum*, with high frequency/cover values of *Equisetum palustre*, *E. telmateja*, *Mentha aquatica,* and the sporadic presence of the rare *Epipactis palustris*. The two *Equisetum* species (particularly *E. palustre*) show sometimes high cover values, becoming the dominant species in this variant.

EQUISETO PALUSTRIS-JUNCETUM EFFUSI Minissale et Spampinato 1990 (Suppl. Material 1, Table S4, rels 23–25, Group 14 in Fig. 2)

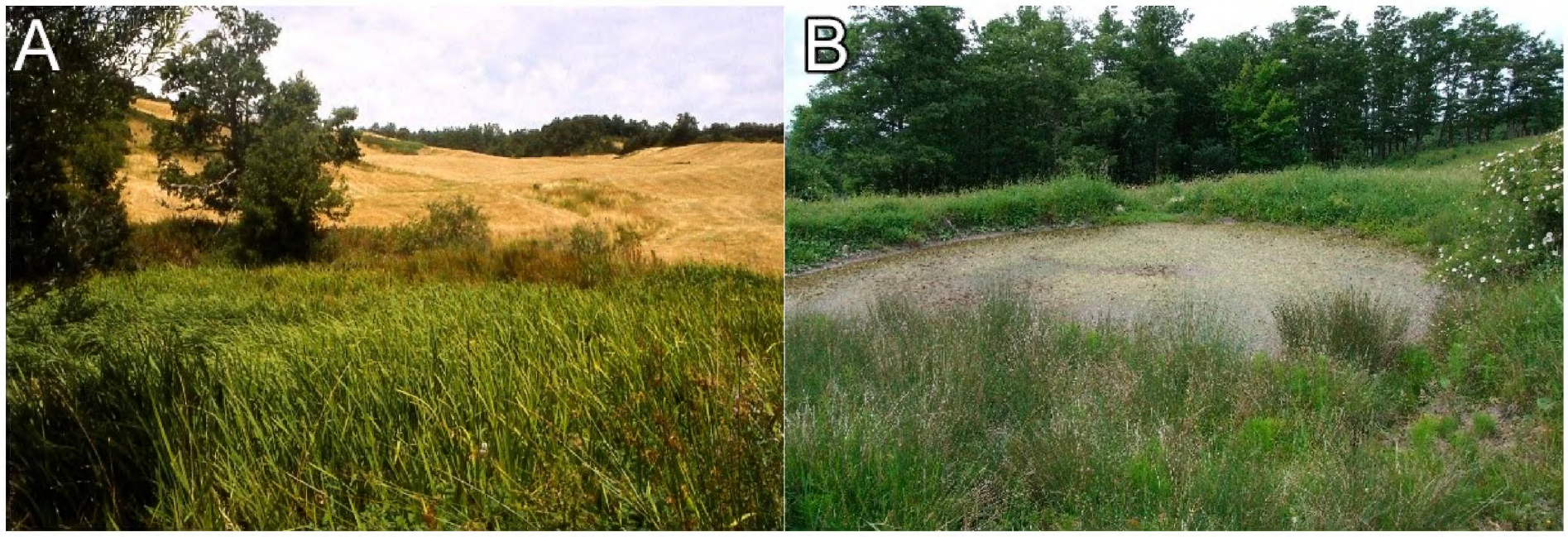

Figure 3. Dense stand of the association *Glycerio-Sparganietum neglecti* Koch 1926 with *Sparganium erectum* L. s.l. (A) and wet meadows of the association *Carici otrubae-Juncetum inflexi* Minissale et Spampinato 1985 with *Juncus inflexus* L. (B). Photo credit: V. Gonnelli, 2012.

This association was described for the higher stretches of an artificial channel in Sicily (Minissale and Spampinato 1990). The association is characterized by the dominance of *Juncus effusus* and by the presence of a conspicuous pool of wet meadow species of the class *Molinio-Arrhenatheretea*, but also of species requiring a high water availability such as *Equisetum palustre*. In the study area, the association was found only at one site on terraces along a stream. The *J. effusus* community of a recently restored wetland is also provisionally attributed to this association, despite some floristic differences, maybe due to the disturbance caused by restoration works.

HERACLEO TERNATI-PETASITETUM HYBRIDI Pedrotti 2008 (Suppl. Material 1, Table S5, rels 1–6, Group 10 in Fig. 2)

We found *Petasites hybridus*-dominated communities along the main streams of the study area and at the edge of marshes shaded by forest vegetation. In the plain or submontane wetlands of Italy, the association *Phalarido-Petasitetum hybridi* Schwick 1933 was often reported (Biondi et al. 2004; Pedrotti et al. 2008; Lastrucci et al. 2010b). According to Pedrotti (2008), in the Apennine mountains, the presence, although rare, of *Heracleum sphondylium* subsp. *ternatum* (= *H. sibiricum* subsp. *ternatum*) in the *P. hybridus* communities allows to differentiate a new association, i.e. *Heracleo ternati-Petasitetum hybridi*. At many sites, the communities appear less floristically defined and they can be interpreted as an impoverished aspect of the association. As far as the alliance classification is concerned, the association was originally attributed to *Aegopodion podagrariae* of the class *Galio-Urticetea* (Pedrotti 2008). The name accepted by Mucina et al. (2016) for this class is *Epilobietea angustifoliae*. In the Italian vegetation prodrome (Biondi and Blasi 2015), the name *Aegopodion podagrariae* is synonymised with *Petasition officinalis*, which is attributed to the class *Galio-Urticetea*. In Mucina et al. (2016), the two alliances are instead both accepted and attributed to two different classes, *Epilobietea angustifoliae* and *Mulgedio-Aconitetea*, respectively. Moreover, the concept of *Petasition officinalis* in Mucina et al. (2016) is restricted to *Carpathian* and Central European areas. For this reason, we consider it appropriate to maintain the attribution of the association to *Aegopodion podagrariae*.

PEPLIS PORTULA community (Suppl. Material 1, Table S6, rels 1–2, Group 3 in Fig. 2)

The only surveyed therophytic hygrophilous community is represented by *Peplis portula* stands, occurring only at two sites. In both cases, this community develops on the edge of pools that are dry up during the summer season. This species acts as a differential or dominant species in various associations of the class *Isoëto-Nanjuncetea*, in the Mediterranean and in Central European areas (Brullo and Minissale 1998; Šumberová and Hrivnák 2013). The almost monophytic stands of the study area can be considered a "basal phytocoenon" according to Poldini and Sburlino (2005) and do not allow any better phytosociological attribution.

Other communities

We found two additional small communities in the humid soils nearby the tall helophytic vegetation. The first community is a *Carex hirta*-dominated wet meadow (Suppl. Material 1, Table S4, rel. 26), with presence of hygrophilous species of the class *Molinio-Arrhenatheretea* (*Juncus effusus*, *J. articulatus*, *Ranunculus repens*), and helophytic species (*Carex pseudocyperus*, *Eleocharis palustris*, *Galium palustre*) and forest species (*Fragaria vesca*, *Geranium nodosum*, *Salix caprea*). This small community shows some affinity to the *Festuco-Caricetum hirtae* O. Bolòs 1962 reported by Carreras et al. (1988), though other authors considered *C. hirta* a species with a low phytosociological diagnostic value (Tomaselli and Bernardo 2006). In our case, the limited extent of the stand suggests considering this vegetation as a transitional aspect between the more hygrophilous communities of the flooded areas and the nitrophilous and forest communities of the habitats further from the water.

The second community is a stand dominated by *Urtica dioica*, developing on shaded and deep soil near woody vegetation and reed bed (Suppl. Material 1, Table S5, rel. 7). This species often forms stands on eutrophic and semi-ruderal habitats (Biondi et al. 2004; Lastrucci et al. 2010b, 2010c, sub *Urtico dioicae-Sambucetum ebuli* (Br.-Bl. in Br.-Bl. et al. 1936) Br.-Bl. in Br.-Bl. et al. 1952) and it plays a role in differentiating a nitrophilous and emerging variant of *Phragmitetum* (Lastrucci et al. 2017a). In the study area, this vegetation type marks the boundary between the communities of wetland habitats (e.g. *Phragmitetum australis*) and the surrounding forests.

Habitat conservation

Marsh communities consisting of helophytes that colonize water bodies and rivers subjected to more or less prolonged submersion, provide many fundamental ecological functions. They provide shelter for fauna, act as a buffer zone between aquatic and terrestrial environments, strengthen the stability of the banks, and host an extremely specialized flora (Ostendorp, 1993; Mishra et al. 2015). In recent times, however, this vegetation has undergone a severe reduction of extent due to anthropogenic factors. Despite this, scientific works pointed out the conservation importance of these environments, especially in southern Europe and the Mediterranean (Angiolini et al. 2017; Landucci et al. 2020; Casavecchia et al. 2021). Nonetheless, some of these habitats are officially considered worthy of conservation at the European level and are listed in the annexes of the Habitats Directive (European Commission 1992; 2013; Biondi et al. 2009, 2012). In particular, among the communities investigated here, only those belonging to classes *Isoëto-Nanojuncetea* and *Epilobetea angustifolii* can be clearly attributed to Natura 2000 habitats (codes 3130 and 6430 respectively, i.e. "Oligotrophic to mesotrophic standing waters with vegetation

of the *Littorelletea uniflorae* and/or of the *Isoëto-Nanojuncetea*" and "Hydrophilous tall herb fringe communities of plains and of the montane to alpine levels"). The communities with *Caltha palustris* have sometimes been considered to be part of the habitat code 7220* "Petrifying springs with tufa formation (*Cratoneurion*)" through the widening of the habitat definition in Habitats Directive 92/43/EEC, (Bassi 2015; Foggi et al. 2017). The communities of *Glycerio-Sparganion* were sometimes considered of local importance, as they are listed in Tuscan regional conservation laws (Tuscan Regional Law no. 56/2000 and no. 30/2015). Other communities, such as many communities of the orders *Phragmitetalia* and *Magnocaricetalia*, have been proposed to become of national and, possibly, European importance in the future instead (see Casavecchia et al. 2021, treated under the name "Freshwater large sedge and reed beds"). Our study highlights the diversity of montane and submontane marsh habitats of Northern Apennines. Despite the important role of natural freshwater ecosystems, many of these communities are still not protected. We argue that our data can be used for biodiversity conservation purpose by supporting further development and the refinement of the Habitats Directive.

Syntaxonomic scheme

PHRAGMITO-MAGNOCARICETEA Klika in Klika et Novák 1941
PHRAGMITETALIA AUSTRALIS Koch 1926
Phragmition australis Koch 1926 nom. corr.
Phragmitetum australis Savič 1926 nom. corr.
Schoenoplectetum lacustris Chouard 1924 nom. mut. nov.
Typhetum latifoliae Eggler 1933
Typhetum angustifoliae Allorge ex Pignatti 1953
MAGNOCARICETALIA Pignatti 1953
Magnocaricion gracilis Géhu 1961
Caricetum vesicariae Chouard 1924
NASTURTIO-GLYCERIETALIA Pignatti 1953
Glycerio-Sparganion Br.-Bl. et Sissingh in Boer 1942
Glycerio-Sparganietum neglecti Koch 1926
Glycerietum notatae Kulczyński 1928 nom. corr.
Glycerietum fluitantis Nowinski 1930 nom. inval.
Beruletum erectae Roll 1938 nom. corr.
OENANTHETALIA AQUATICAE Hejný ex Balátová-Tuláčková et al. 1993
Eleocharito palustris-Sagittarion sagittifoliae Passarge 1964
Eleocharitetum palustris Savič 1926

MONTIO-CARDAMINETEA Br.-Bl. et Tx. ex Klika et Hadač 1944
CARDAMINO-CHRYSOSPLENIETALIA Hinterlang 1992
Caricion remotae Kästner 1941
Caricetum remotae Kästner 1941
Cardamine amara community
Caltha palustris community

ISOËTO-NANOJUNCETEA Br.-Bl. et Tx. in Br.-Bl. et al. 1952
NANOCYPERETALIA Klika 1935
Peplis portula community

MOLINIO-ARRHENATHERETEA Tx. 1937
POTENTILLO-POLYGONETALIA AVICULARIS Tx. 1947
Potentillion anserinae Tx. 1947
Carici otrubae-Juncetum inflexi Minissale et Spampinato 1985
variant with *Juncus effusus*
variant with *Equisetum palustre*
Equiseto palustris-Juncetum effusi Minissale et Spampinato 1990
Carex hirta community

EPILOBIETEA ANGUSTIFOLII Tx. et Preising ex von Rochow 1951
CIRCAEO LUTETIANAE-STACHYETALIA SYLVATICAE Passarge 1967
Urtica dioica community
Aegopodion podagrariae Tx. 1967
Heracleo ternati-Petasitetum hybridi Pedrotti 2008

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Supplementary material 1

Tables S1-S6

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Data type: tables

Explanation note: Phytosociological tables

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Appendix I

Site abbreviation	Site name	Lat (°)	Long (°)	Elevation m a.s.l.	Inclusion in protected areas (PNFC: National Park of Foreste Casentinesi; SAC: Special Area of Conservation, followed by SAC code)	Reference to published data
A	Asqua	43.796.280	11.788.290	823	PNFC; SAC IT5180002	
Be	Beccia	43.708.990	11.916.770	951		
Cam	Camarelle	43.685.020	12.107.370	954		
F	Fangacci di Campigna	43.867.267	11.735.892	1,325	PNFC; SAC IT4080001	
FC	Fonte Sodo dei Conti	43.880.308	11.711.449	1,547	PNFC; SAC IT4080001	
Fe	Ferraiolo	43.684.557	12.116.995	972		
FG	Fonte del Ghiaccio	43.687.699	12.099.813	952		
G	Gorga Nera	43.877.920	11.684.560	1,286	PNFC; SAC IT5180002	
IV	Il Vinco palude	43.716.132	11.910.581	800		
La	Lama	43.829.913	11.838.356	710	PNFC; SAC IT4080001	
LI	Lago degli Idoli	43.864.070	11.691.800	1,374	PNFC; SAC IT5180002	
LP	Lago Pianacci	43.722.410	11.903.240	628		
LT	La Trappola	43.664.895	12.076.409	658		
LV	Lago del Vinco	43.716.100	11.910.390	801		
MA	La Maiolica	43.721.578	11.914.147	788		
MC	Monte Cavallo	43.677.850	12.105.150	834		
MP	Metaleto pantano	43.791.732	11.815.021	903	PNFC; SAC IT5180018	
MV	Monte Verde	43.673.010	12.126.460	1,028	SAC IT5180010	
P	Fonte Porcareccio	43.836.055	11.795.912	1,390	PNFC; SAC IT4080001	
PB	Poggio Bonetto	43.734.896	11.973.090	996	SAC IT5180005	
PC	Pozza del Cervo	43.830.055	11.816.984	1,176	PNFC; SAC IT4080001	
PE	Pantano dell'Eremo	43.811.217	11.809.832	1,046	PNFC; SAC IT5180018	
PF	Prato al Fiume	43.812.819	11.808.751	1,052	PNFC; SAC IT5180018	
PG	Passo Gualanciole	43.736.775	11.981.465	1,077	SAC IT5180005	
Pi	La Pianca	43.740.670	12.119.170	1,030		Relevés from Lastrucci et al. (2005)
Poz	Pozzolo	43.667.500	12.114.140	910		
Pr	Pratelle	43.738.880	11.986.410	969	SAC IT5180006	
Prt	Pratalino	43.720.980	11.928.450	966	PNFC; SAC IT5180005	
PS	Poggio Sambuco	43.684.190	12.117.610	1,001		
PStr	Pozza delle Strosce	43.618.460	11.952.540	1,345		
PT	Pantano Traversari	43.807.340	11.819.490	1,072	PNFC; SAC IT5180018	
St	Stammerina	43.807.650	11.858.550	1,110	PNFC; SAC IT5180018	
T	Laghetto Traversari	43.807.340	11.819.490	1,077	PNFC; SAC IT5180018	
To	Il Toro	43.719.860	11.951.320	1,032	SAC IT5180007	